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INNOVATIVE TECHNOLOGY
Summary Report

Cesium Removal Using Crystalline Silicotitanate

Tanks Focus Area

Prepared for
U.S. Department of Energy
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INNOVATIVE TECHNOLOGY
Summary Report

Cesium Removal Using Crystalline Silicotitanate

OST Reference #21

Tanks Focus Area

Demonstrated at
Hanford Site
Richland, Washington
and
Oak Ridge Reservation
Oak Ridge, Tennessee

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

Technology Summary

Approximately 100 million gallons of radioactive waste is stored in underground storage tanks at the Hanford Site, Idaho National Engineering and Environmental Laboratory (INEEL), Oak Ridge Reservation, and Savannah River Site (SRS). Most of the radioactivity comes from ^{137}Cs, which emits high-activity gamma radiation. Of all types of radiation produced by the waste, gamma radiation has the greatest penetrating power. It can result in high dose rates to workers and requires dense materials such as lead for shielding. Gamma radiation complicates the handling and disposal of these tank wastes. If the cesium is removed, most of the waste can be treated and disposed of as low-activity waste (LAW). This approach represents significant cost savings and volume reduction over disposal as high level waste (HLW). A combination of laboratory-scale tests and an engineering-scale demonstration of the Cesium Removal System demonstrated a viable option for removal of cesium from radioactive waste.

The Cesium Removal System is a modular, transportable, ion-exchange system configured as a compact processing unit. The ion-exchange system operates much like a home water softener. Liquid tank waste flows through columns packed with solid material, called a sorbent, that selectively adsorbs cesium and allows the other materials to pass through it (see Figure 1). The resulting waste stream can be treated as LAW. The sorbent is crystalline silicotitanate (CST), an engineered material with a high capacity for sorbing cesium from alkaline wastes.

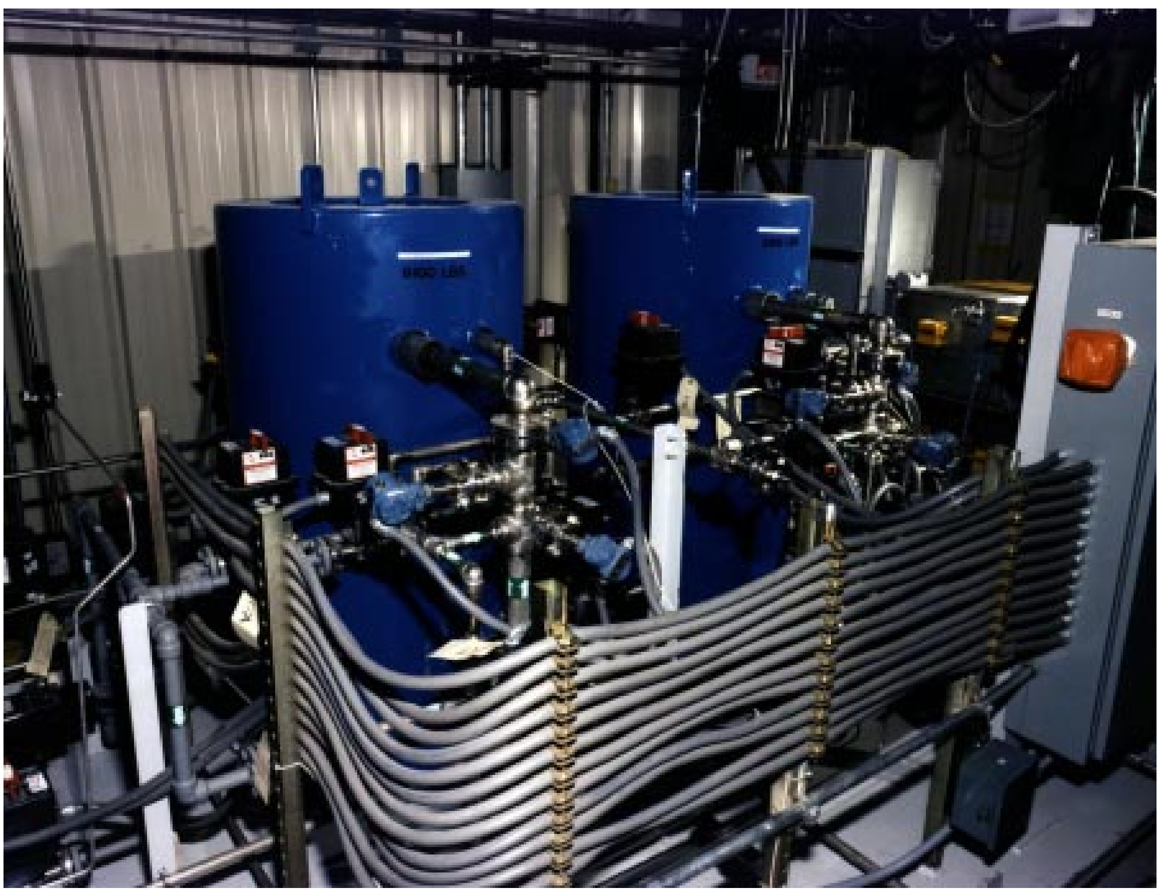

Figure 1. Cesium Removal System - This view shows the ion-exchange columns with the unit shielding installed and the pipes coming through the shielding. Unit shielding cuts down on the total shielding requirements and makes hands-on maintenance of equipment outside the columns much easier.

Cesium removal by ion exchange is applicable to all tank wastes in the U.S. Department of Energy (DOE) complex. Without cesium removal, the entire waste volume would be treated as HLW, and the cost for treatment and disposal of the waste would be prohibitive. Other methods have been considered for cesium removal. However, ion exchange offers advantages of new, high-capacity sorbents and the ability to deploy a modular system in existing facilities.

Demonstration Summary

DOE investigated ion-exchange materials for many years; however, process demonstrations were needed. In 1995, a promising ion-exchange material, Ionsiv® IE-911, became commercially available. The Cesium Removal System was demonstrated at Oak Ridge using Melton Valley Storage Tank (MVST) waste for feed. Demonstration operations began in September 1996 and were completed during June 1997. Prior to the demonstration, a number of ion-exchange materials were evaluated at Oak Ridge with MVST waste. Also, three ion-exchange materials and three waste types were tested at Hanford. These bench-scale tests were conducted in a hot cell. Hanford's results showed that 300 times less sorbent was used by selecting Ionsiv IE-911 over organic ion-exchange resins for cesium removal.

Ionsiv IE-911 is a CST sorbent developed jointly by DOE and industry. Ionsiv IE-911 was initially developed by Texas A&M University and Sandia National Laboratories. Advanced development was funded by DOE's Efficient Separations Program and the Hanford Tank Waste Remediation System. The engineered form of CST (30/60 mesh pellets suitable for use in conventional ion-exchange columns) was commercialized by UOP Corporation. The skid-mounted Cesium Removal System was designed and fabricated by TTI Engineering.

Approximately 15% of the cesium-loaded ion-exchange material from the MVST demonstration was sent to SRS for vitrification in a hot cell. CST vitrification studies demonstrated the ability to incorporate this material into HLW glass. The remainder of the loaded sorbent was packaged for shipment to the Nevada Test Site (NTS) for disposal as a final waste form.

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All published Innovative Technology Summary Reports are available at http://em-50.em.doe-gov. The Technology Management System, also available through the EM-50 web site, provides information about the Office of Science and Technology (OST) programs, technologies, and problems. The OST Reference Number for Cesium Removal Demonstration is #21.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The Cesium Removal System is an ion-exchange process that can safely and efficiently remove cesium from tank wastes. The basic principle of ion-exchange technology is that ions in solution are electronically charged and can be attracted to locations on a solid that have an opposite charge. The solid is called a sorbent, and the locations are called binding sites. A sorbent with high affinity for a particular ion is said to be selective for that ion. When a waste solution contacts a sorbent, ions with low affinity are exchanged for ions with high affinity.

Adsorbed ions can often be eluted from ion-exchange material by contacting the sorbent with a solution of a different pH. Some sorbents bind certain ions very strongly, however, and are considered nonregenerable. Typically, polymeric resin-based sorbents are regenerable and inorganic ion-exchangers are non-regenerable. Both types of have been tested at the bench scale with actual waste from tanks at DOE sites. The tests showed many advantages to using inorganic ion exchangers. The inorganics have remarkable selectivities for cesium, and they are more resistant to chemical, thermal, and radiation degradation.

Engineering-Scale Demonstration of Cesium Removal System

The Cesium Removal System used at Oak Ridge is a modular system configured as several transportable units. It can be deployed at or near existing waste storage tanks. It was designed and fabricated by a commercial vendor, TTI Engineering of Walpole, Massachusetts. For the Oak Ridge demonstration, the system was set up inside the 7877 Building near the MVSTs at Oak Ridge National Laboratory (ORNL). The arrangement of processing units is shown in Figure 2.

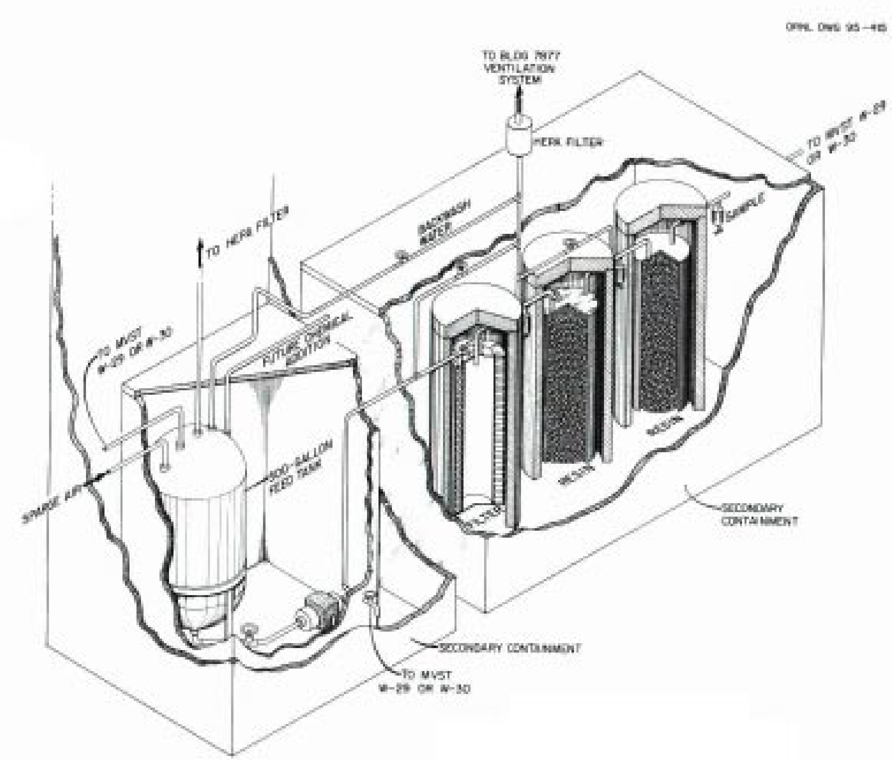

Figure 2. Cesium removal system arrangement.

The feed tank module contained a 500-gal feed tank and two pumps. The ion-exchange module contained a filter unit and two ion-exchange columns. Each column was a 12 in diameter by 40 in high and held about 10 gal of sorbent. A sorbent sluicing/drying skid contains equipment to remotely transfer sorbent to and from the columns and to dry spent sorbent in preparation for disposal.

Waste was transferred to the system through existing transfer lines, and cesium decontaminated waste was returned to the tanks for continued storage. Portable shielding material was placed around the ion-exchange columns and process modules to control radiation exposure. The system was remotely operated from a control room in a nearby building.

Hot Cell Testing of Proposed Cesium Removal Technology at Oak Ridge

Before deploying the engineering-scale system for treatment of actual waste, a bench-scale, continuous-flow ion-exchange system was set up in a hot cell at ORNL. The system was used to test commercially available cesium removal sorbents with actual MVST waste. The objective of this work was to obtain performance data to support sorbent selection for the engineering-scale demonstration and to predict performance of the larger-scale system.

The system employed a 10-milliliter (ml) ion-exchange column with all associated tanks, filters, pumps, and instrumentation needed to run continuous-flow tests (see Figure 3). Several sorbents (e.g. CS-100, resorcinol formaldehyde, and potassium cobalt hexacyanoferrate) were tested for their ability to decontaminate the supernatant to very low cesium levels and adsorb significant quantities of cesium. Based on the results, Ionsiv IE-911 was selected for the engineering-scale demonstration.

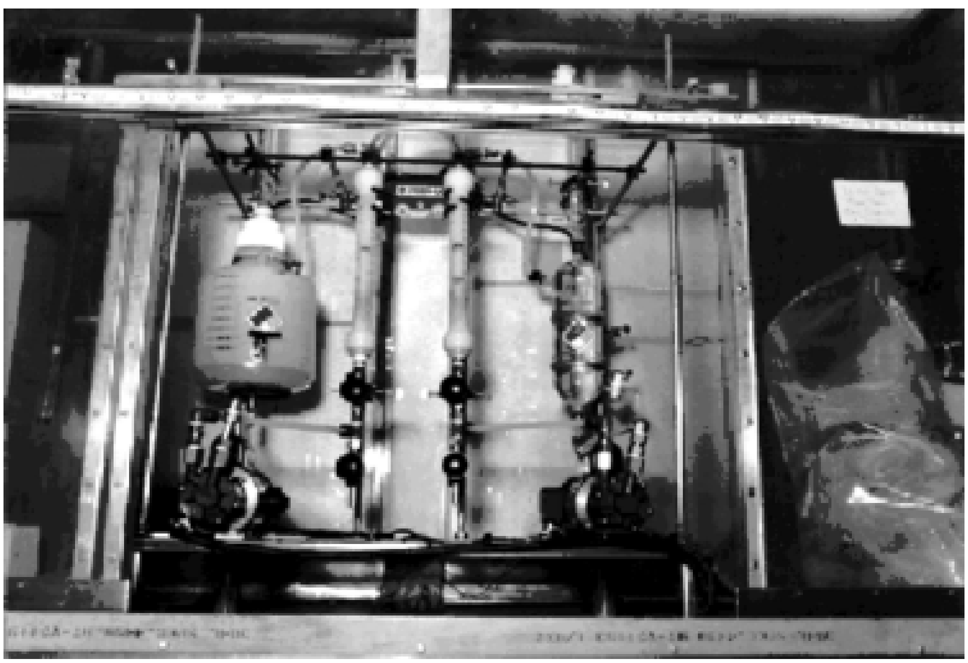

Figure 3. Bench-scale ion-exchange system installed in hot cell at Oak Ridge.

Cesium breakthrough curves for the full scale system agreed well with results from the hot-cell tests, indicating that bench scale column tests can be used to reliably predict actual plant scale operating conditions.

Bench-Scale Continuous-Flow Testing with Hanford Wastes

A separate but related task was the bench-scale, continuous-flow testing of cesium removal sorbents in a hot cell using actual Hanford wastes. The objective of this task was to evaluate sorbent performance with different Hanford waste types. Comparisons could also be made with results from bench-scale and engineering-scale demonstrations with ORNL's MVST waste. Three high-performance cesium adsorbers were evaluated, including Ionsiv IE-911. Three different Hanford waste types were tested: double shell slurry feed (DSSF), complexant concentrate (CC), and dissolved saltcake (DSC).

The bench-scale system used three columns in series with a total ion-exchange volume of about 18 ml. Tank waste supernatant was diluted to about 5 molar sodium concentration and passed through the system at a predetermined flow rate. During ion exchange, flow rate is typically measured in the number of column volumes of liquid passing through the column per hour. Removal efficiency is usually expressed as the total volume of feed treated (in column volumes) before effluent cesium concentration exceeds a preselected level (e.g. 50% breakthrough). This is an important factor in determining the number and size of ion-exchange columns needed to treat large volumes of waste on a production scale.

System Operation

Table 1 summarizes the system operational requirements for the Cesium Removal System.

Table 1. Summary of the system operation requirements

Special operational parameters	It may be necessary to stop loading the resin before it reaches full capacity to meet the Waste Acceptance Criteria of the selected disposal site.
Materials, energy, other expendable items	Standard utilities are required. Facilities for interim storage and transport of cesium-loaded material are required.
Personnel requirements	The personnel operating the process must have knowledge of the technology and remote handling skills.
Secondary waste stream	Loaded CST resin cannot be eluted and must be disposed as radioactive waste.
Potential operational concerns and risks	System must be shielded to protect workers from excessive radiation exposure.

SECTION 3

PERFORMANCE

Demonstration Plan

Cesium removal is required at DOE sites to reduce the radiation emitted by liquid tank wastes, but operational experience with ion-exchange processes for cesium removal is needed. Moreover, DOE decided the ability to process supernatant in small facilities available on an as-needed basis near a tank site needed to be demonstrated. Therefore, the DOE deployed a compact processing unit for demonstrating the Cesium Removal System at Oak Ridge.

The primary objectives of the demonstration were as follows:

- demonstrate operability of an engineering-scale, continuous-flow system for cesium removal from tanks;
- evaluate the effectiveness of Ionsiv IE-911 sorbent for removing cesium from actual tank waste;
- process 25,000 gal of radioactive MVST supernatant;
- concentrate the cesium in a small-volume, solid waste form suitable for disposal;
- provide loaded sorbent to SRS for vitrification tests;
- demonstrate the use of modular equipment in existing facilities;
- decontaminate the equipment for hands-on maintenance and transport to other sites; and
- assure loaded sorbent could be packaged to meet waste acceptance criteria for NTS.

Hot start-up of the Cesium Removal System began September 15, 1996, and waste processing was completed on May 16, 1997. Approximately 31,000 gal of MVST supernatant at Oak Ridge was processed, and 1,142 curies of cesium were removed and loaded onto 70 gal of Ionsiv IE-911 sorbent. Laboratory tests showed the loaded sorbent was suitable for disposal at NTS and no further stabilization was necessary to meet waste acceptance criteria.

System Performance

Engineering-Scale Demonstration of Cesium Removal System

The demonstration highlighted the high cesium capacity of Ionsiv IE-911 when compared on an equivalent basis to other promising sorbents for treating tank wastes. Ionsiv IE-911 required about 20 times less sorbent than CS-100 and about 7 times less sorbent than resorcinol-formaldehyde (RF) resin. The high capacity of Ionsiv IE-911 for cesium allowed single-pass operation. In contrast, regenerable ion exchangers such as CS-100 may require multiple elution/regeneration cycles to remove an equivalent amount of cesium.

The engineering-scale demonstration at Oak Ridge provided the private sector experience in design and fabrication for processing radioactive waste. The demonstration also provided performance data for comparison with bench-scale tests and to develop scale-up factors. The feasibility of mobile, modular systems as a lower-cost alternative to permanent, fixed facilities for treatment of radioactive waste was also effectively demonstrated.

Hot-Cell Demonstration of Proposed Cesium Removal Technology

As noted in Section 2, hot-cell tests were used to compare the performance of a number of cesium ion-exchange materials and form the basis for the selection of a sorbent for the engineering-scale demonstration. Sorbents evaluated in the hot cell testing included the following:

- RF resin,
- SuperLig® 644C resin,

- 3M WWL WEB with SuperLig 644 embedded,
- Eichrome KCoFeC sorbent,
- CS-100 resin, and
- CST engineered form (Ionsiv IE-911).

The sorbents were tested at three flow rates and, where applicable, through a series of five loading/elution/regeneration cycles.

Cesium-loading breakthrough curves and elution curves were generated as a result of the tests. Operational observations and characteristics were also recorded for each material. An example of comparative results obtained in evaluating the six candidate ion exchangers appears in Table 2. These data show the relative ability of the sorbents to remove cesium by noting the volume of MVST supernatant processed before reaching 50% cesium breakthrough, meaning the point at which cesium concentration in the column effluent reaches 50% of the concentration in the column feed.

Table 2. Results of the hot-cell tests with ORNL supernatant

Sorbent	Feed flow rate (column volumes/h)	50% Breakthrough (column volumes of supernatant)
RF Resin	7	48
SuperLig 644C	6	100
3M WEB	50	60
KcoFeC	9	250
CST-38B (IE-911)	6	342
CST-38B (IE-911)	3	350
CS100	3	18

These results show Ionsiv IE-911 surpassing all other sorbents tested. It should be noted that Ionsiv IE-911 is an inorganic exchanger and is non-regenerable for cesium removal. Breakthrough curves for the full-scale system agreed well with hot cell tests, indicating that hot cell column tests can be used to reliably predict scale-up and actual operating performance.

Bench-Scale Continuous-Flow Testing with Hanford Wastes

Bench-scale, continuous-flow column tests were also performed with selected solvents using Hanford wastes. Much of the challenge of treating Hanford waste lies in the fact that there are several waste types. Characteristics of the liquid waste types are described in Table 3. Taken together, these represent approximately 125 million gal of waste feed when pretreated to 5 molar sodium concentration.

Table 3. General characteristics of Hanford supernatant wastes

Waste type	Description	Characteristics
DSSF	Double Shell Slurry Feed	High sodium (~10 molar). Some phosphate and sulfate. Moderate radioactivity.
CC	Complexant Concentrate	High sodium. Up to 45 grams/liter organic. Soluble strontium and transuranics.
NCAW	Neutralized Current Acid Waste	5 molar sodium. High radioactivity.
DSC	Dissolved Saltcake	Diluted to 5 molar sodium. Phosphate and sulfate present. Low radioactivity

The Hanford tests were run with three different waste types, three of the same sorbents tested at ORNL, and similar processing conditions. Due to the high radioactivity involved with the quantities of waste to be treated, all tests were performed in a hot cell at the Hanford site. Results of the testing are shown below:

Table 4. Hot-cell test results with Hanford waste

Waste type	Column volumes to 50% cesium breakthrough (λ_{50})		
	Ionsiv IE-911	SuperLig 644	RF Resin
DSSF (101-AW)	660	not tested	14
CC (107-AN)	1044	120	not tested
DSC (U-109, U-108)	570	190	not tested

As can be seen from this table, the Ionsiv IE-911 can process significantly larger volumes of waste than the regenerable, organic ion-exchange materials tested. One disadvantage of a nonregenerable solvent for Hanford wastes is that the loaded solvent is considered HLW and must therefore meet repository disposal requirements. One way to ensure meeting this requirement would be to incorporate the loaded Ionsiv IE-911 into HLW glass.

Vitrification of Loaded Ion-Exchange Materials

The Savannah River Technology Center developed borosilicate glass formulations incorporating up to 65 wt % Ionsiv IE-911. Acceptable glasses were produced without forming crystalline phases that would affect glass durability. These results were significant in that the current limit of 1 wt % titania in HLW was exceeded by nearly 20 times with no observed impact on product quality. When the sorbent was added to simulated Defense Waste Processing Facility (DWPF) feed, glass meeting waste acceptance product specifications was produced containing up to 28 wt % sludge oxides and 10 wt % sorbent.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

Within the DOE complex, there are hundreds of tanks containing tens of millions of gallons of highly radioactive supernatant along with solid saltcake and sludge. Additional radioactive liquids are created when the saltcake is dissolved and the sludge is mobilized and washed. Wastes at Hanford, SRS, INEEL, and Oak Ridge contain significant concentrations of radioactive cesium. Approximately 50 million gal of supernatant and crystallized salt wastes will require cesium removal prior to treatment and disposal.

Current radionuclide removal plans for the major DOE sites with underground storage tanks include the following:

- *Oak Ridge:* Liquid tank wastes containing high levels of radionuclides are being treated in facilities operated by the private sector. Plans include disposal of the final waste form at NTS, the Waste Isolation Pilot Plant, or an alternative location proposed by the private contractor.

- *SRS:* Methods to remove cesium are being evaluated. In the past, tank supernatant was treated by in-tank precipitation (ITP). ITP uses sodium tetraphenylborate to precipitate cesium and sodium titanate to absorb soluble strontium. The process was suspended because of safety concerns.

- *INEEL:* The proposed baseline is to separate liquid waste and dissolved calcine into high-activity and low-activity fractions for separate treatment and disposal. Extensive radionuclide removal operations are planned. The low-activity fraction will be grouted for disposal, and the high-activity fraction will be immobilized in glass and disposed of in the HLW repository.

- *Hanford:* Specific technologies to be employed will be selected by private waste-treatment vendors. Cesium removal from supernatant will be required. Both organic and inorganic solvents are being considered. Technetium may also be removed from supernatant, probably by ion exchange. Decontaminated supernatant will be vitrified and disposed on site. HLW sludge, with cesium and technetium added back in, will be vitrified for disposal in the national HLW repository.

- *West Valley:* Cesium was removed from supernatant at the site in New York using an inorganic zeolite ion exchanger. The loaded zeolite is being vitrified along with HLW sludge.

Ion-exchange processes are being used or planned at many of these sites. Ion exchange offers several advantages for performing cesium and strontium removal. The process can be either continuous or in-tank batch operations. Decontamination factors of many orders of magnitude can be achieved. The process introduces no hazardous chemicals into the waste stream. The compact processing unit concept demonstrated at Oak Ridge is simple and can be implemented as a mobile waste-treatment system.

Technology Integration Opportunities

Multisite applicability of the compact processing unit concept is being demonstrated through multiple deployments of the Cesium Removal System as part of an Accelerated Site Technology Deployment project. During FY99, the Cesium Removal System will be operated in series with the Mobile Evaporator at Oak Ridge to decontaminate and reduce the volume of tank waste supernatant prior to treatment and disposal. The volume of supernatant to be grouted for disposal at the NTS will be reduced by approximately 260,000 gal between 1998 to 2002. Up to 50% waste volume reduction will be achieved (DOE-OR 1997).

Another possible application of the Cesium Removal System is the DWPF recycle stream. The DWPF at SRS converts HLW into glass logs by vitrification. Liquid wastes from the melter off-gas scrubber system and other facility sources are currently recycled to the HLW tanks at rate of about 3 million gal per year. A project is underway to design an integrated system to remove cesium, mercury, and solids from the recycle stream. This system would greatly reduce the volume of waste recycled to the tanks and allow the decontaminated liquid to be processed through SRS's Liquid Effluent Treatment Facility.

Technology Maturity

The Cesium Removal System is being implemented at DOE sites after several years of testing and demonstration. Project planning for the engineering-scale demoonstration began in FY95. System design specifications were prepared, private sector capabilities were evaluated, and detailed design of the Cesium Removal System was completed. Hot-cell testing in support of the demonstration system design and operation was conducted at ORNL during FY95 through FY97. Hot-cell testing of cesium removal from Hanford waste was conducted during FY96 and FY97.

In FY96, the Cesium Removal System was fabricated by industry. The system was installed at Oak Ridge, it was cold tested, and hot (radioactive) operations were initiated. The demonstration was completed in FY97, and decontamination and demobilization were initiated. The D&D phase was completed in FY98.

In late FY97, efforts were initiated to combine the Cesium Removal System with the Mobile Evaporator System. This integrated approach improves the efficiency of treating liquid waste streams at ORNL and other potential deployment sites.

Patents/Commercialization/Sponsors

The Cesium Removal System was designed and constructed, under a competitively bid contract, by TTI Engineering, Inc. of Walpole, Massachusetts. Ion-exchange systems have been designed for many other industrial applications. However, special considerations apply in building systems for radioactive service.

The ion-exchange material used in the engineering-scale demonstration was Ionsiv IE-911, an engineered form of CST. This exchanger was initially developed by researchers at Sandia National Laboratories and Texas A&M University. Advanced development was supported by DOE's Efficient Separations and Processing crosscutting program and Hanford's Tank Waste Remediation System. Commercial development of Ionsiv IE-911, the engineered form of CST, was done by UOP, Inc. of Des Plaines, Illinois.

SECTION 5

COST

Methodology

Life-cycle cost savings are calculated by comparing the cost of the innovative technology to the cost of the previous alternative. The yearly cash flow is estimated, and a real discount rate of 3.5% is used (Appendix C, February 1997, of OMB circular No. A-94, 10-year real interest rates on Treasury Notes and Bonds). The alternative is grouting the supernatant without cesium removal. The innovative technology is the Cesium Removal System.

Cost Analysis

Capital costs of $9.1 million are estimated in Table 5 for the FY97 demonstration and the combined Modular Evaporator and Cesium Removal System modifications in FY99 and FY00. Capital costs for the Cesium Removal System are described by Walker et al. (1998). Costs for research and development are estimated from the OST Technology Management System.

Table 5. Approximate capital costs of Cesium Removal System at Oak Ridge

Component	Cost ($ thousands)
Research and development	4,200
Initial system equipment and installation	3,800
System modification	1,100

Operating costs for the initial demonstration and operation of the combined system deployed at ORNL are outlined in Table 6. In FY97, approximately $2 million was spent to demonstrate the Cesium Removal System, ship cesium-loaded sorbent to SRS, conduct chemical and data analysis, develop summary reports, and initiate decommissioning of the system. Between January 1998 and October 1998, the Mobile Evaporator was upgraded to operate in series with the Cesium Removal System. In FY 1999 and 2001, the integrated system will concentrate or decontaminate liquid waste prior to transfer to the new tanks.

Table 6. Operating costs for Cesium Removal System in $ thousands

Task	FY97	FY98	FY99	FY00	FY01
Design and process support		300			
Operation	1,900	700	2,100	900	
Waste certification and disposal		100	400	300	900
Decommission					500
Total	**1,900**	**1,100**	**2,500**	**1,100**	**1,400**

Cost Savings Versus Alternative Technologies

From 1998 through 2001, removal of the cesium allows the concentrated supernatant to be more economically processed into an acceptable waste form. If the cesium is not removed, a larger volume of waste must be packaged and sent to NTS. Immobilizing the waste in the MVST through privatization will occur between FY 2002 and 2006. The volume of waste to be grouted is 520,000 gal for the grouting scenario and 260,000 gal using the Mobile Evaporator/Cesium Removal System. The evaporator reduces the volume of waste by 50%.

It is estimated to cost $50 per gal of supernatant processed if cesium is removed (including treatment, transportation, and NTS charge). It is estimated to cost $150 per gal (including treatment, transportation, and NTS charge) of supernatant processed if cesium is not removed (Robinson and Homan 1997).

Cost Conclusions

The data compiled in Table 7 indicate that the constant 1999 dollar cost for supernatant treatment with cesium removal at Oak Ridge is approximately $30 million. Without cesium removal the costs would be over $70 million. This represents a cost savings of approximately $40 million at Oak Ridge.[1]

Cesium removal has large potential for additional savings across the DOE complex. For example, SRS's DWPF produces a process condensate stream from the melter off-gas scrub system. This stream is about 1 million to 3 million gal per year. The average radionuclide concentrations are high enough that the liquid must be recycled to the HLW tanks and treated through evaporation. Cesium removal will allow the decontaminated condensate stream to be routed directly to the SRS Effluent Treatment Facility. The cost avoidance is estimated to be tens of millions of dollars.

Cesium removal using the CS-100 resin is the baseline at Hanford. Cost savings for cesium removal at Hanford using Ionsiv IE-911 resin instead of CS-100 resin is estimated to be almost $200 million for Phase I and $900 million for Phase II (Demuth 1997). This savings is from reduced HLW volume because there is less sodium in the HLW feed when Ionsiv IE-911 resin is used.

[1] The cost savings were calculated from the difference in the net present value of the baseline and innovative technologies. The net present value is calculated by discounting the constant dollar cash flows using a discount factor of 3.5% (OMB constant-dollar discount rate, January 1998).

Table 7. Comparision of treatment and disposal costs in constant $1999 for Oak Ridge baseline operating costs versus Cesium Removal System in $ thousands

Baseline		Cesium Removal System	
Supernatant treatment and disposal (520,000 gal @ $150/gal)	78.0	Research and development	4.2
		Capital costs	5.0
		Operating costs	5.6
		CST disposal	1.7
		Decommission	0.5
		Supernatant treatment and disposal (260,000 gal @ $50/gal)	13.0
Total	**78.0**		**30.0**

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

The Cesium Removal System was demonstrated in DOE's EM-30 facilities. For the Cesium Removal System demonstration, the regulators included the Tennessee Department of Environment and Conservation and the Environmental Protection Agency Region 4. In addition, Oak Ridge relied on the Southern States Energy Board and the Rapid Commercialization Initiative to obtain multistate regulatory perspectives and facilitate technology demonstration and deployment within multiple regulatory jurisdictions. Regulatory considerations addressed for the demonstration included the following:

- *Assessment of Safety Hazards:* A joint team of personnel from various ORNL organizations determined that the demonstration was outside the scope of DOE Order 425.1, Start-up and Restart of Nuclear Facilities, since the project was a continuation of an existing process and did not introduce new safety hazards. However, a readiness self-assessment was performed. Start-up approval was granted through the DOE Readiness Review Process. Evaluations addressed safety requirements, the National Environmental Policy Act (NEPA), the Clean Air Act, the Clean Water Act, and Resource Conservation and Recovery Act (RCRA) regulations required in this process.

- *RCRA Permitting Requirements:* Liquid waste was not discharged by the Cesium Removal System because the liquid was returned to the MVSTs at Oak Ridge. However, if the modular evaporator is operated in conjunction with the Cesium Removal System, it must be operated such that the evaporator distillate meets the Process Waste Treatment Plant Waste Acceptance Criteria. At ORNL, this process is covered by a RCRA permit-by-rule since the discharge to secondary waste treatment facilities is covered by a National Pollutant Discharge Elimination System (NPDES) permit.

- *Air Permits:* The only source of air emissions from the Cesium Removal System is off-gas from the feed tank. For the demonstration, this was exempted from permitting requirements under Air Pollution Control exemption rule 120-3-9 (4)(ff) for "All storage tanks with a capacity of less than 10,000 gallons, except those containing gasoline." This exemption applies under the condition that any radionuclide emissions from the source results in an off-site whole body dose of less than 0.1 millirem per year at the nearest DOE property line. Depending on the volume of the feed tank in a full-scale treatment system, this exemption might not apply. The Cesium Removal System is ventilated through the existing ventilation system in Building 7877 at ORNL which is currently permitted by the Tennessee Department of Environmental and Conservation Air Pollution Control Division for the Liquid Waste Solidification Process.

- *NEPA Review:* A NEPA categorical exclusion was obtained to conduct the demonstration at Oak Ridge. It was also determined that the demonstration is exempted from RCRA permitting and operating requirements as long as the wastewaters treated are on-site Oak Ridge wastewaters.

The specific regulatory permits and documentation required for the project were developed with regulators so that minimal updates and modifications will be required if the system is used in future operations. Permit requirements for implementation of this technology at other facilities will need to generally address solid, liquid, and gas wastes and could be expected to include: RCRA permitting, NEPA review, air permits,and Radioactive Materials License.

The cesium-loaded ion exchange materials remaining after processing must be managed as a radioactive waste. Management of HLW, transuranic waste, and low-level waste is addressed by DOE Order 5820.2a. This order is being replaced by DOE Order 435.1.

Prior to disposal, the cesium-loaded ion exchange material must meet the Waste Acceptance Criteria of the selected disposal site. Protocols for the acceptance and transportation of HLW are still being developed.

As with all complex treatment processes, open lines of communication between regulators, stakeholders, and DOE sites facilitate efficient projects.

Safety, Risks, Benefits, and Community Reaction

The safety, risk, and community reaction of this technology are summaried below:

- *Worker Safety:* Radiological exposure to personnel must be kept "as low as reasonably achievable" (ALARA), pursuant to DOE regulations. Removing the cesium from stored wastes reduces worker exposure during the grout stabilization process and subsequent handling and transportation of the waste. Fully containing, shielding, and automating the process also minimizes worker exposure to hazardous materials and process hazards.

- *Community Safety:* The risk to the community is very low. The physical process has a very low accident and release potential.

- *Community Acceptance:* The technology has minimal labor force impact. However, the process can result in positive economic impact by reducing the cost of waste processing and disposal.

- *Stakeholders:* There is no adverse public or tribal input regarding the Cesium Removal System. In fact, the technology is readily understandable to the public.

- *Aesthetic:* The system is compact (approximate size 15 ft x 15 ft x 15 ft). It is anticipated that system will typically be housed in existing structures.

- *Land Use:* The system will not affect land designated for unrestricted use.

- *Natural Resources:* The process does not consume significant amounts of natural resources or significantly impact natural resources for future use. The process uses readily available electric energy.

Benefits of the technology are summarized below**:**

- *Lower Radiation Exposure to Workers:* The process itself is highly shielded and automated and does not result in high exposures. Workers involved in subsequent processing, treatment, and handling have lower radiation exposure because the radioactivity of the material they are handling has been reduced.

- *Reduced Waste Handling Costs:* Cesium removal allows many wastes to be managed as contact-handled wastes, which is significantly less expensive than remote handling.

- *Reduced Disposal Costs:* Disposal costs for HLW are much higher than for LAW. The cesium removal process concentrates HLW into a smaller volume, and the majority of the waste volume can receive less expensive LAW disposal.

- *Secondary Waste Minimization:* The two products of the Cesium Removal System are a small volume of HLW and the original volume of LAW. There is no net increase in volume. Existing technologies and disposal systems can handle the low-level fraction.

- *Low Maintenance Costs:* The system is designed to require minimal maintenance for at least the first year of operation. A radioactive maintenance facility is required for repair of the equipment.

SECTION 7

LESSONS LEARNED

Implementation Considerations

Multisite deployments of environmental technologies at DOE sites have encountered some unexpected barriers. Project personnel for the Cesium Removal System were committed to ensuring successful implementation of the technology at other DOE sites. In ORNL's experience with this demonstration, close cooperation with personnel from other sites has facilitated the transfer of knowledge and experience. Close communication includes

- visiting ORNL during operating periods,
- addressing technical and regulatory issues of multiple sites early in technology development,
- participating in demonstrations,
- hands-on training on equipment, and
- access to data generated on the projects.

Another goal of the Cesium Removal System demonstration was to develop the necessary regulatory permits and documentation with enough flexibility to streamline future updates as equipment or processes change. The project team believed that future implementation of the technology could depend on ease of permitting.

Technology Limitations and Need for Future Development

The inherent size constraints of a compact processing unit somewhat limit its ability to process waste at high flow rates. This unit may not be able to accommodate certain processes due to constraints on equipment size.

DOE must efficiently process the 100 million gal of radioactive liquid waste and sludges stored across the complex with a minimum investment of time, funding, and new facility construction. To maximize efficiency, ORNL plans to demonstrate the Cesium Removal System with the Mobile Evaporator. Together, the technologies provide a cost-effective solution to separate highly radioactive material from bulk waste and reduce final waste volumes.

Despite the high capacity of CST, it may be necessary to stop loading the resin before it reaches full capacity. This is to ensure that loaded sorbent does not exceed the waste acceptance criteria for the selected disposal site. The waste acceptance criteria at NTS include the following requirements:

- Each resin package will contain less than the Class C limit of 4,600 Curies $^{137}Cs/m^3$.
- The loaded sorbent will be transported in Type B transfer casks.

The number of packages transferred during a shipment must be set to remain below the allowable Department of Transportation exposure limits.

APPENDIX A

REFERENCES

Demuth S. F., and D. Williams. 1997. *Cost effectiveness of crystalline silicotitanate and resorcinol-formaldehyde ion exchange resins, and enhanced sludge washing with and without chromium oxidation.* LA-UR-97-3903, Rev. 1. Los Alamos, NM.: Los Alamos National Laboratory.

Robinson, S. M., and F. J. Homan. 1997. *Cost comparison for REDC Pretreatment Project.* ORNL/TM-13433. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

U.S. Department of Energy, Oak Ridge Operations. November 1997. Table 1. "Accelerated technology deployment project costs" in *Modular evaporator and ion exchange systems for waste reduction in tanks Accelerated Technology Deployment Plan,* p 37.

Walker, J. F., et al. March 1998. *Cesium Removal Demonstration utilizing crystalline silicotitanate sorbent for processing Melton Valley Storage Tank supernate: final report.* ORNL/TM-13503. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

APPENDIX B

LIST OF ACRONYMS

ALARA	as low as reasonably achievable
ASTD	Accelerated Site Technology Deployment
CC	Complexant Concentrate
CST	crystalline silicotitanate
DOE	Department of Energy
DSC	dissolved saltcake
DSSF	double-shell slurry feed
DWPF	Defense Waste Processing Facility
HLW	high-level waste
INEEL	Idaho National Engineering and Environmental Laboratory
ITP	in-tank precipitation
LAW	low-activity waste
MVST	Melton Valley Storage Tank
NEPA	National Environmental Policy Act
NTS	Nevada Test Site
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
RCRA	Resource Conservation and Recovery Act
RF	resorcinol-formaldehyde
SRS	Savannah River Site
TFA	Tanks Focus Area